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Design and predicting efficiency of highly nonlinear hollow cylinders switched reluctance motor

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Abstract

The conventional designs of switched reluctance motors (SRMs) with multi-rotor teeth contain some shortcomings. For example, the shaft fills a relatively high volume inside the SRM without a commensurable contribution to the output torque. In addition, the conventional toothed rotor SRM produces high torque ripples and has high iron losses compared to most electrical machines due to the switching process between the phases. These facts shaped the motivation for devising a new design of SRM. This design is intended to employ a rotor that rotates inside the stator without a shaft. In addition, the reluctance of the air gap is graded such that it produces output torque with low ripples. The new design must have a stator excited in a manner that allows the currents to pass in one direction only in each section of the stator to minimize the iron losses. This paper discusses the design steps of the new SRM that has a rotor consisting of two hollow iron cylinders and a stator excited in a way that allows a one directional current flow. The design steps are presented and estimates of the losses are presented as a means of evaluating the efficiency of the new design.
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Keywords: Switched reluctance motors; Air gaps; Output torque; Material losses

1. Introduction

High reliability, fault tolerance, efficiency in speed variation and robust construction are only a few advantages of the switched reluctance motor (SRM). These advantages give this design the edge in many applications [1]. The SRM is inherently nonlinear and always works in a transient mode with no steady state operations due to the switching process between the phases [2]. The last characteristic induces high ripples in the output torque [3]. The conventional toothed rotor, fitted on the shaft, fills a big volume inside the SRM that never contributes to produce any output torque [4]. Switching on/off between the different phases is required to run the motor, and the running speed depends on the frequency of switching. The switching process is the main reason for the high iron losses of the SRM [5]. To overcome all these problems, it is necessary to change the magnetic circuit topology to conceive a new design of the SRM that can rotate without shaft, has low ripples and has low losses.

The paper introduces the required new design, which is the hollow cylindrical rotor SRM. In this design, there is no shaft, and the cylindrical rotor is designed to grade the air gap, and consequently the reluctance; that reduces ripples in the torque characteristic [6,7]. The cylinders are hollow to make the rotor light enough to run at high speeds. The stator of the new SRM is designed to allow the current to pass in one direction, which significantly reduces the iron losses. Each coil in the stator fills two neighbouring slots in an attempt to reduce the end windings copper losses. The result of that is improved design operational efficiency by reducing copper usage [8,9].

Generally, SRMs have been considered the simplest of all electric machines; however, it needs to be designed accurately to give competitive performance and output

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torque [10]. Because of the high nonlinearity of the SRM performance, this paper uses adaptive finite elements in order to obtain an accurate prediction of the performance [11].

The losses in the SRM consist mainly of the stator copper losses and the core losses. The copper losses are proportional to the square of the r.m.s current, whereas the core losses are a function of the excitation frequency and the flux density. Unlike conventional a.c. variable speed motors, the components of the SRM core are not subjected to the same frequency of flux. Furthermore, the current waveform is not sinusoidal and is dependent on operating conditions. The fact that the SRM mostly operates in varying degrees of saturation further complicates the estimation of the core losses. This paper describes the procedure of determining the losses in the new hollow rotor SRM. The procedure is comprehensive because it begins with the fundamentals of the flux distribution in the different iron parts and proceeds to the final estimation of the losses. It provides a complete, clear and concise path to a successful estimation of the losses in this type of new SRM [12]. Finally, the paper assesses the new design in light of its output torque, performance and efficiency [10].

2. Background about improvement in output torque due to the new design

Fig. 1 shows a cross section of the rotor of a conventional SRM. The shaft occupies a relatively large volume without producing a proportional torque, shaft size is for mechanical purposes only. Also, the rotor in this toothed shape produces high torque ripples [10,13]. So, it is necessary to design a new rotor that can rotate inside the SRM without a shaft and produces output torque with low ripples [14].

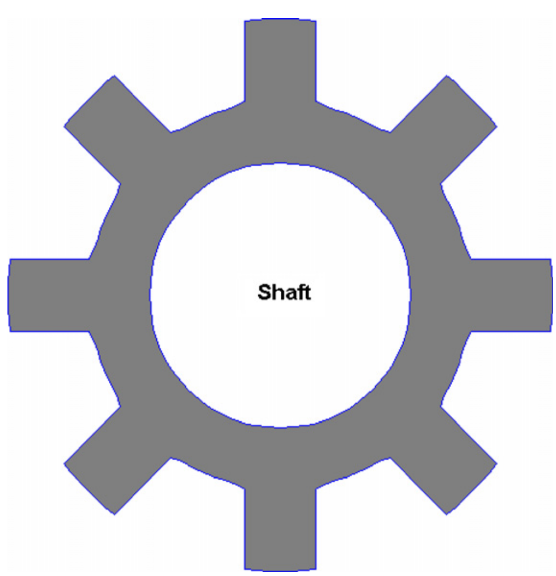

Fig. 1. Cross-section of a rotor of a conventional SRM.

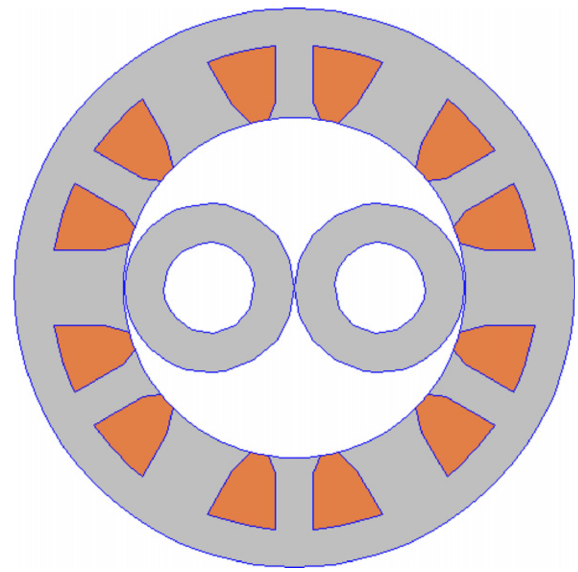

Fig. 2. Cross-section of the proposed new SRM.

Fig. 2 shows a cross section in the proposed new design of the SRM. In this design, the rotor consists of two cylinders. The rotor topology is entirely changed. There is no need for a shaft, and the air gap is graded to reduce the output torque ripples [15]. The stator has six wide teeth to increase and concentrate the flux crossing from the stator to the rotor and six thin teeth as return flux teeth.

Fig. 2 shows the surface of the cylindrical rotor collecting flux from the air gap more than the surface of the toothed pole of the conventional design, so the flux linkage of the rotor of the new design is increased [16,17].

To clarify this fact, a model of the new design and another for the equivalent conventional SRM are built by the adaptive finite element approach to compare their output torques. The equivalent conventional SRM refers to the conventional SRM that has the same: number of poles, number of phases, outside diameter, rotor diameter and axial length [18].

Fig. 3 shows a conventional SRM with toothed rotor, where the stator has 12 teeth and the rotor has 2 teeth. The machine has the standard design; the width of the rotor tooth has the same width as the stator tooth. The machine is short pitch (each coil links one stator tooth).

Figs. 3 and 4 show the conventional and the new designs of the SRM, respectively. Fig. 5 shows a comparison between the characteristics of the two machines. From the fundamentals of any SRM, the area enclosed between the aligned and the unaligned positions is proportional to the output torque. In Fig. 5, the area between the aligned and the unaligned positions of the new hollow rotor SRM is greater than the area in the case of the conventional design. This observation is explained by two reasons: first, the surface of the new pole is greater

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